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NUCLEAR EXPLOSIVE SAFETY

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WORKSHOP 2015

Bhopal Revisited

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Why Bhopal?

India

- Madhya Pradesh (state) was underdeveloped
- Hoped to stimulate economy
- Encourage “western” industries to build in the picturesque, lakeside, town to provide jobs

Union Carbide

- Difficult to expand insecticide production in United States due to environmental legislation
- Annual rent was \$40 per acre
- Low wages, few benefits
- Eager workforce

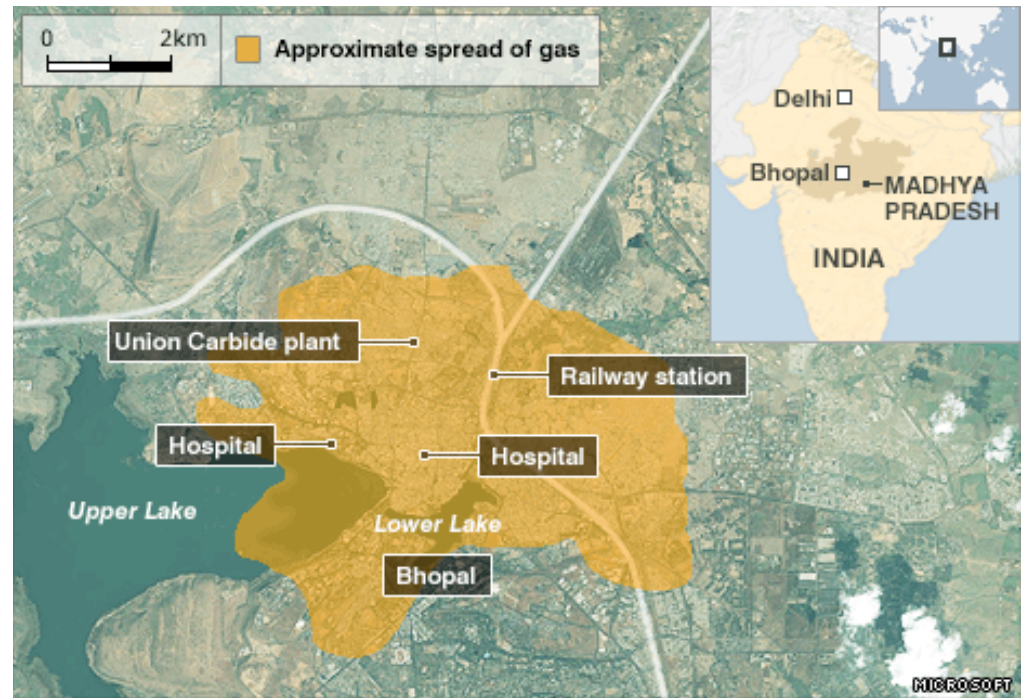
The Facility

- Construction began in 1970
- Union Carbide India, Ltd. formed, 50.9% owned by Union Carbide USA
- Very successful startup
- Part of “India’s Green Revolution”
- Initial Staff – 1000 employees



The Surroundings

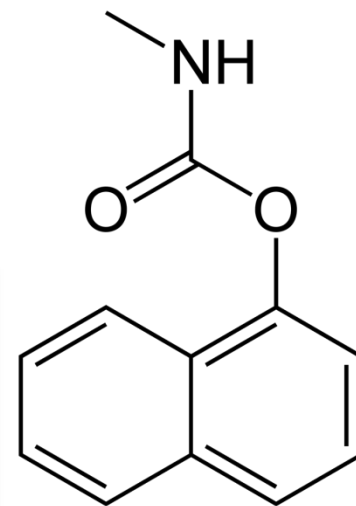
- Originally a suburb, low population density
- “Squatters” began to gather around the facility for work, and jobs associated with the facility
- The town itself began to expand in the area



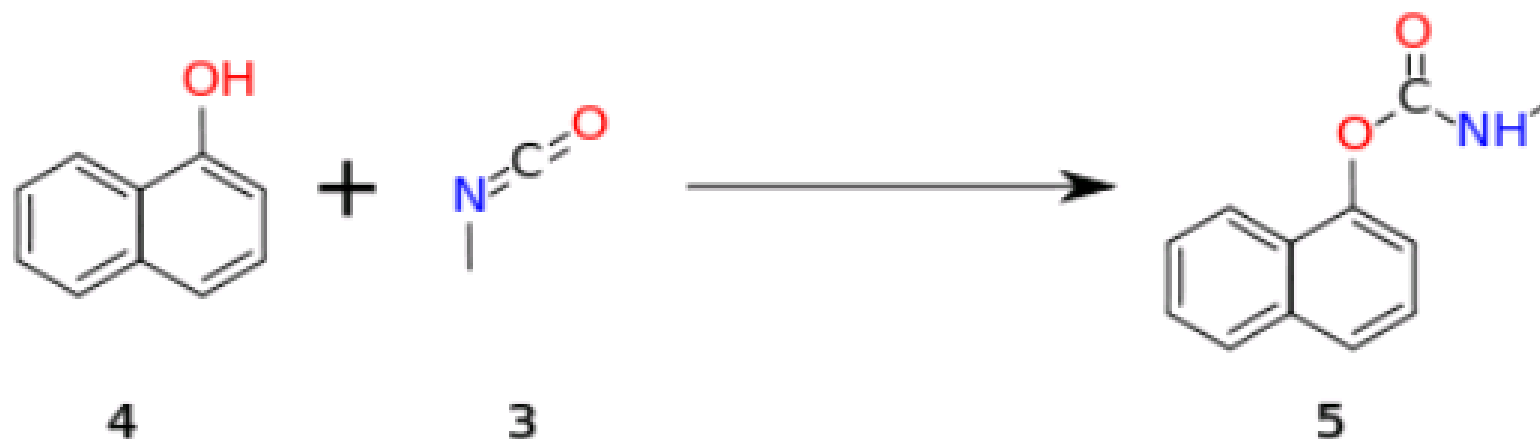
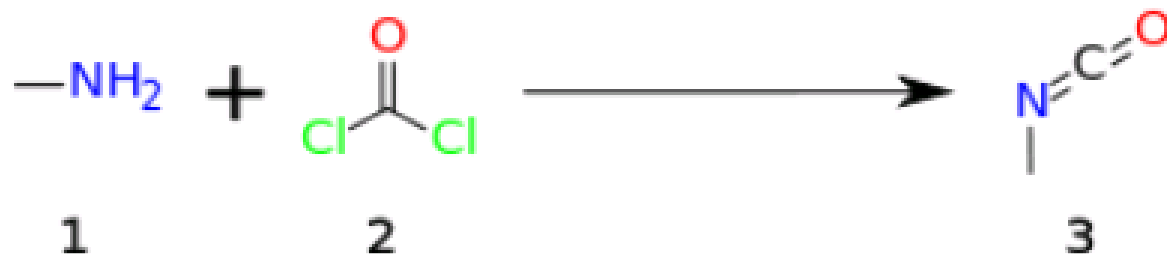
Product Details

- Produced carbaryl pesticide
 - DDT (dichlorodiphenyltrichloroethane) substitute

Carbaryl (1-naphthyl methylcarbamate) is a chemical in the carbamate family used chiefly as an insecticide. It is a white crystalline solid commonly sold under the brand name **Sevin**, a trademark of the Bayer Company. Union Carbide discovered carbaryl and introduced it commercially in 1958. Bayer purchased Aventis CropScience in 2002, a company that included Union Carbide pesticide operations. It remains the third-most-used insecticide in the United States for home gardens, commercial agriculture, and forestry and rangeland protection. About 11 million kilograms were applied to U.S. farm crops in 1976.



The Chemistry



Methylamine (1) reacts with phosgene (2) producing methyl isocyanate (3) which reacts with 1-naphthol (4) to yield carbaryl (5)



MIC

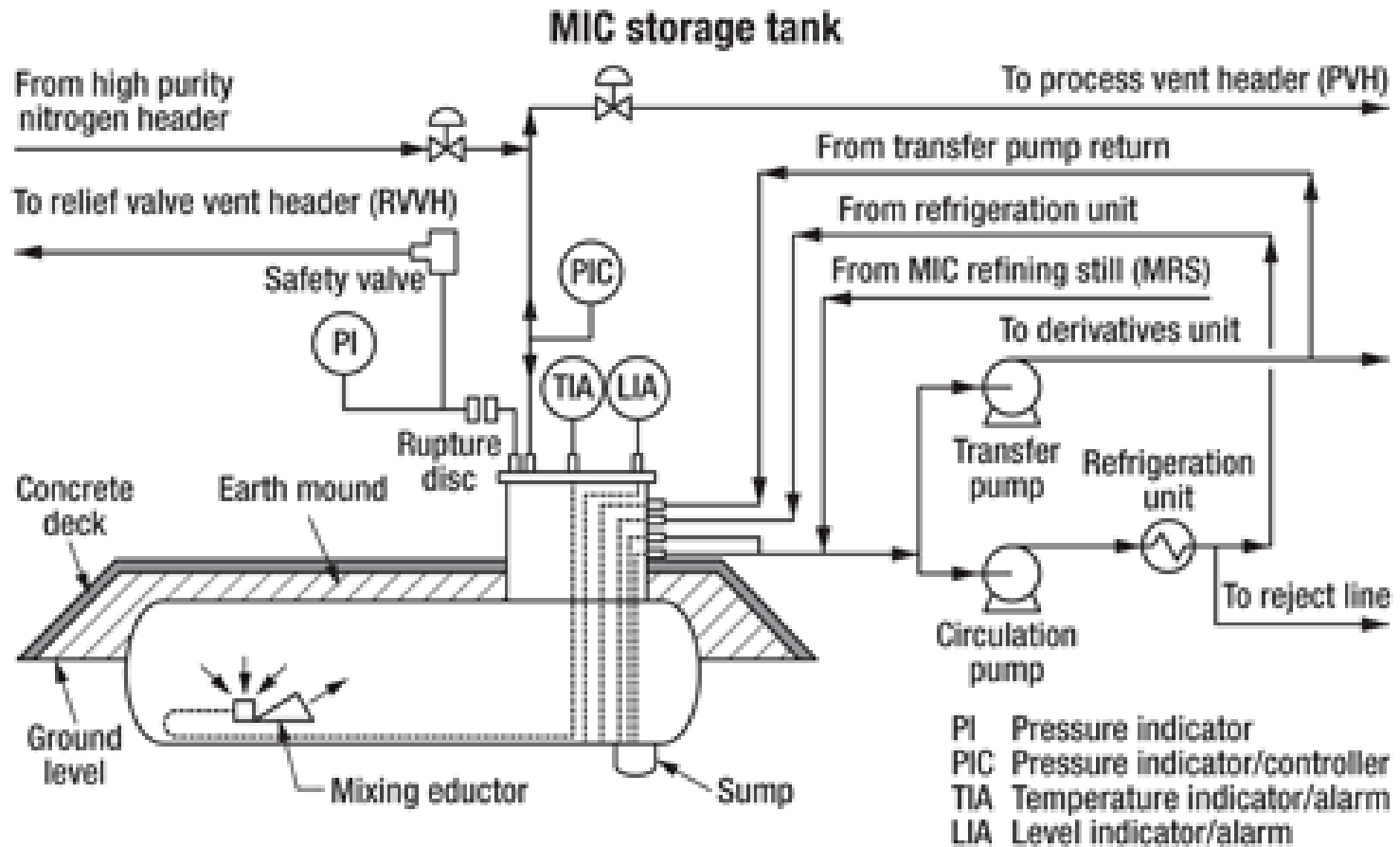
- Union Carbide began producing methyl isocyanate (MIC) in Bhopal, India, on February 5, 1980.
- MIC is a highly reactive intermediate chemical that Union Carbide used to manufacture various pesticides. It is also a very lethal substance that can be harmful or fatal if inhaled or absorbed through the skin. MIC reacts exothermically with a variety of potential contaminants including rust and particularly water.



MIC - 2

- MIC reacts with normal Carbon Steel
- Requires use of nitrogen blanket on unprotected pipes, tanks and valves
- MIC produced was stored in two stainless steel storage tanks, designated as Tanks 610 and 611. An identical tank (Tank 619) received contaminated material from either Tank 610 or 611 on an emergency basis
- A nitrogen blanket was used to maintain slight pressure inside the MIC storage tanks while continuously purging MIC vapor into the process vent header (PVH).

MIC Storage



The End is Not the Beginning

- This accident occurred years before it occurred...





Leaving Home Base

- The factory suffered from a series of chronic MIC leaks.
 - MIC could therefore not safely be released into the environment.
- Although the transfer pumps were provided to export MIC into the derivatives unit, there is no record of their use at any time while the factory was in operation.
 - Instead, an alternative transfer method was developed that excluded the pumps.



Adapted Process

- This method involved raising the MIC storage tank pressure to at least 14 psig with nitrogen.
- Under these conditions, the MIC would reverse-flow directly into the derivatives unit through the alternative pathway.
- This practice minimized the potential for transfer pump seal failures to expose factory workers to the lethal process.
 - Unfortunately, over time, this lead to corrosion in the valves, process vent header, gages, and piping.



Compensating for Adaptation

- The corrosion led to revised and new procedures...
- This prompted the creation of a maintenance procedure to remove MIC trimer deposits by flushing with water.
 - But this process was damaging the seals in the refrigeration system....
- On January 7, 1982, provided a maintenance opportunity to “upgrade” the original metallic seal with a more fouling resistant, but weaker ceramic seal.



Compensating ... More

- On January 9, 1982, the fragile ceramic substitute seal was shattered in an unprecedented catastrophic failure.
 - This failure produced a massive MIC release that sent about 25 workers to the hospital with serious injuries.
- On January 12, 1982, a formal notice was issued to declare that the refrigeration system was being shut down.
 - In doing so, a third non-standard operating procedure was introduced: running the plant without MIC refrigeration.

One Last Straw...

- After shutting down refrigeration system, the MIC storage temperature varied from about 15°C to 40°C.
 - This new operating range exceeded the 11°C MIC storage tank high temperature alarm in the control room. Therefore, the high temperature alarms were disconnected.
 - Likewise, the actual temperature inside the tank was unknown after shutting down the refrigeration system because the control room temperature gauge was not scaled for operation above +25°C.



Help Arrives!

- In April 1982, factory workers complained... publicly.
- In May 1982, a corporate team from the U.S. came to investigate
 - The audit report formalized several recommendations
 - Install Nitrogen purge system with low flow alarms at an alternative MIC system venting into the PVH should be installed
 - Install dual seals on centrifugal pumps
 - Provide water spray protection for the MIC pumps for cloud suppression



Help Leaves!

- The audit team complimented the factory's creative approach to improving workplace safety with nonstandard operating and maintenance procedures.
 - Accordingly, the factory's safety manuals were rewritten in 1983 and 1984 to reflect actual operation without MIC refrigeration.



Accident - Stage 1

- On the evening of December 2, 1984, the vent lines were corroded and choked with MIC trimer deposits.
- The pipes were being flushed with water to remove the MIC trimer deposits.
 - MIC trimer deposits form in the presence of rust.
 - Rust forms on carbon steel pipes not protected by an inhibitor.
 - The inhibitor (nitrogen) was isolated from the PVH and RVVH in order to pressurize the MIC storage tanks.
 - The MIC storage tanks were pressurized to bypass the transfer pumps.



Accident – Stage 2

- Due to either operator error or a valve failure, water entered Tank 610, which contained over 40 tons of MIC.
 - Under normal circumstances, this would have activated the tank's high temperature alarm.
 - But the high temperature alarm was disconnected when the refrigeration system was shut down.
 - The control room MIC temperature gauge could not be trusted because it normally read above scale without refrigeration.
 - The refrigeration system was shut down almost three years before the incident because pump seal failures exposed factory workers to the hazardous process.



Accident – Stage 3

- The contamination event inside Tank 610 remained hidden while the reaction mixture temperature continued rising.
- The MIC storage tank was leaking and pressure increased as the reaction mixture evolved more vapors.
 - Although the control room pressure gauge seemed to be within normal range for a sealed tank, the tank was not sealed.
 - Therefore, contamination was not detected until a thermal runaway reaction took place, which sent the tank's pressure gauge off scale.



Accident – Stage 4

- Contributors to the outcome (mitigating controls that failed):
 - Plant vent gas scrubber (on the flare tower) was not operational.
 - The system was shut off due to a corroded valve.
 - The plant “water curtain” spray was designed to shoot a fog of water over the tanks. The curtain was intended to go 100 feet in the air. At the time of the accident, the spray was shooting 40 feet in the air.
 - One of the pressure pumps had failed and was removed and never replaced due to the cost of the pump.
 - The flare tower, which was designed to burn the venting gas at altitude, was not operational.
 - A pipe connecting the vapor collection system to the tower had been removed for maintenance, and not reported to the control room.

▪



How bad was it?

- Estimates vary on the death toll.
 - The official immediate death toll was 2,259.
 - The government of Madhya Pradesh confirmed a total of 3,787 deaths related to the gas release.
 - A government affidavit in 2006 stated that the leak caused 558,125 injuries, including 38,478 temporary partial injuries and approximately 3,900 severely and permanently disabling injuries.
 - Others estimate that 8,000 died within two weeks, and another 8,000 or more have since died from gas-related diseases.



Remember Bhopal

- When you choose not to investigate a chronic failure
- When the right choice is not the most economical choice
- When designing a solution that manages a hazard instead of eliminating it
- When tempted to execute a procedure the way you think it should be written instead of how it is actually written
- When thinking about substituting engineered equipment with people
- When redesigning a system to make it “safer”
- When making changes for the sake of improving personal safety



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